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EVALUATION OF RESULTS OF U.S. CORN AND SOYBEANS EXPLORATORY EXPERIMENT - CLASSIFICATION PROCEDURES VERIFICATION TEST

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16. Abstract

The U.S. Corn and Soybeans Exploratory Experiment — Classification Procedures Verification Test was undertaken to evaluate the classification procedure utilized in making crop proportion estimates for corn and soybeans using remotely sensed data. The procedure was derived during the Transition Year of the Large Area Crop Inventory Experiment in the Earth Observations Division at the NASA Lyndon B. Johnson Space Center. Analysis of variance techniques were applied to classifications performed by 3 groups of analysts who processed 25 segments selected from 4 agrophysical units (APU's). Group and APU effects were evaluated to determine factors which affected the quality of the classifications. The classification results were evaluated to determine the effectiveness of the procedure in producing corn and soybeans proportion estimates.

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TECHNICAL REPORT

EVALUATION OF RESULTS FROM THE U.S. CORN AND SOYBEANS EXPLORATORY EXPERIMENT — CLASSIFICATION PROCEDURES VERIFICATION TEST

Job Order 74-402

This report describes Accuracy Assessment activities of the Foreign Commodity Production Forecasting project of the AgRISTARS program.

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Space and Life Sciences Directorate

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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HOUSTON, TEXAS

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PREFACE

The investigation which is the subject of this document was undertaken in support of the Foreign Commodity Production Forecasting project of the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing program. Under Contract NAS 9-15800, scientists of Lockheed Engineering and Management Services Company, Inc., evaluated the results which are reported for the Earth Observations Division, Space and Life Sciences Directorate, of the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center.

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1. INTRODUCTION

The purpose of the U.S. Corn and Soybeans Exploratory Experiment — Classification Procedures Verification Test was to evaluate the performance of the adapted Large Area Crop Inventory Experiment (LACIE) Transition Year (TY) classification procedure for corn and soybeans. See reference 1 for a discussion of the procedure used in this test. In this test, 25 segments selected from four agrophysical units (APU's) were processed by three groups of analysts. Analysis of variance techniques were used to determine the factors which were important to the quality of the classifications performed. The factors evaluated were group effects and APU effects. The classification results were evaluated to determine the effectiveness of the procedure in producing corn and soybeans proportion estimates.

2. FACTORS AFFECTING THE QUALITY OF THE CLASSIFICATIONS

The segments used in this test were from APU's 14, 24, 25, and 28 located in Missouri, Iowa, Illinois, and Indiana. Because APU 24 had a small number of segments and APU's 14 and 24 were reasonably similar, APU's 14 and 24 were merged and designated APU 14 for evaluation purposes.

Three groups of analysts processed the segments. Group I processed 19 of the segments, whereas groups II and III each processed 18 segments. The allocation of the segments among the groups and APU's is shown in table 1. The linear model and related assumptions used in the analyses of variance are described in reference 2.

The following measures of classification quality were used in the analyses of variance:

a. Proportion estimation error

b. Percentage of picture elements (pixels) correctly classified

c. Reduction in the expected proportion estimate variance if a bias correction were applied to the classification results

d. Analyst dot labeling accuracy

The factors were tested for their effects in the following order: first, interaction between groups and APU's; second, group effects; and, third, APU effects. If a significant result was obtained at one stage, it was impossible to test for significant results at a later stage.

Table 2 shows the average proportion estimation error and average absolute proportion error for corn and soybeans by group and by APU. Significant differences are indicated by numbers in parentheses following the values. No significant effects were found in the results for corn. For soybeans, a significant difference in the proportion errors was found between groups II and III. The absolute proportion error was significantly different for APU 14.

TABLE 1.- DISTRIBUTION OF SEGMENTS BY GROUP AND BY APU

[Parentheses indicate processed data which were not used in the analyses of variance]

APU	Segment number	Group I	Group II	Group III
14	135	X		X
	202	(X)	(X)	(X)
	864		X	X
	565	X		X
	877	X	X	
	880		X	X
	881	X	X	(X)
	882	(X)	(X)	(X)
25	107	X	X	
	141	X		X
	144		X	X
	205	X	X	
	800	(X)	(X)	
	807		X	X
	809	X		X
28	123	X	X	
	127	(X)	(X)	(X)
	133		X	X
	832	X		X
	837	(X)	(X)	(X)
	842	X	X	
	843	(X)	(X)	
	852	X		X
	853	(X)		(X)
	860		X	X

TABLE 2.- PROPORTION ESTIMATION ERRORS

[Significant differences are indicated by number in parentheses following the values]

	Corn		Soybeans	
	Average error, %	Average absolute error, %	Average error, %	Average absolute error, %
Group I	-6.3	7.4	-6.6	7.4
Group II	-3.1	8.[illegible]	-9.0(1)	9.0
Group III	-4.8	7.1	-4.0(1)	7.0
APU 14	-5.8	7.4	-2.3	4.5(2)(3)
APU 25	-3.6	5.9	-7.3	9.0(2)
APU 28	-4.8	9.3	-9.9	9.9(3)
Overall	-4.7	7.5	-6.5	7.8

The results for the percentage of pixels correctly classified are shown in table 3. An interaction between groups and APU's for the percentage of correct classification (PCC) for class "other" made it impossible to determine group and APU effects for the PCC for "other." The only significant result was a group effect for the PCC for corn, where the group III result was significantly different from the group I and II results.

The results of reductions in variance are shown in table 4. In analyzing the results for corn, a significant interaction between groups and APU's made it impossible to test for group and APU effects individually. There were no significant effects for soybeans.

Tables 5 and 6 show the dot labeling accuracy for type 1 and type 2 dots. There were group effects for the type 1 dot labeling accuracy for corn and for the overall category. In both cases, group III was significantly different from groups I and II. A significant APU effect was shown for the labeling accuracy for class "other" in both the type 1 and type 2 dots. In both cases, APU 14 was significantly different from APU's 25 and 28.

In summary, the observed group effects involved dot labeling accuracy and PCC for corn. In both cases, group III was consistently less accurate than groups I and II. Since all three groups were given the same training and were to follow the same procedures, it would appear that there was some misunderstanding of the procedure for corn by group III.

The observed APU effects involved dot labeling accuracy and proportion estimation error for soybeans. In both cases, APU 14 had less accurate results than APU's 25 and 28. It appears that dot labeling for soybeans is more difficult in APU 14. It is interesting to note that, although the dot labeling for type 1 dots showed a significant difference, the PCC for the classifications based on these dots did not show a significant difference.

TABLE 3.- PERCENTAGE OF PIXELS CORRECTLY CLASSIFIED

[Significant differences are indicated by number in parentheses following the values]

	Corn PCC	Soybeans PCC	"Other" PCC	Overall PCC
Group I	73.2(1)	64.2	72.1	72.6
Group II	75.6(2)	52.5	68.7	70.8
Group III	62.6(1)(2)	53.9	75.6	68.4
APU 14	77.8	59.9	67.1	72.4
APU 25	69.9	49.8	72.2	70.3
APU 28	63.6	60.9	77.1	69.2
Overall	70.4	56.9	72.1	70.6

TABLE 4.- PERCENTAGE OF REDUCTION IN VARIANCE EXPECTED IF BIAS CORRECTION IS PERFORMED ON CLASSIFICATION RESULTS

	Corn	Soybeans
Group I	61.0	53.2
Group II	62.8	59.3
Group III	61.6	59.5
APU 14	58.9	55.4
APU 25	62.2	59.2
APU 28	64.3	57.4
Overall	61.8	57.3

TABLE 5.- TYPE 1 DOT LABELING ACCURACY

[PCL = percentage of dots correctly labeled; significant differences are indicated by the number in parentheses following the values]

	Corn PCL	Soybeans PCL	"Other" PCL	Overall PCL
Group I	88.3(1)	79.9	89.5	86.8(3)
Group II	89.2(2)	76.2	88.3	86.8(4)
Group III	67.0(1)(2)	66.1	85.8	77.8(3)(4)
APU 14	83.5	83.3	76.9(5)(6)	83.5
APU 25	85.9	65.1	89.6(5)	82.7
APU 28	75.1	73.8	97.1(6)	85.1
Overall	81.5	74.1	87.9	83.8

TABLE 6.- TYPE 2 DOT LABELING ACCURACY

[PCL = percentage of dots correctly labeled; significant differences are indicated by the number in parentheses following the values]

	Corn PCL	Soybeans PCL	"Other" PCL	Overall PCL
Group I	66.9	70.4	85.9	74.9
Group II	70.5	60.6	86.5	74.3
Group III	64.5	61.1	80.7	70.9
APU 14	70.8	72.8	76.6(1)(2)	73.6
APU 25	70.7	61.8	89.3(1)	76.3
APU 28	60.5	57.5	87.2(2)	70.3
Overall	67.3	64.0	84.4	73.4

3. CLASSIFICATION PROCEDURE EVALUATION

In order to determine the effectiveness of the classification procedure in producing proportion estimates, the various stages in the classification procedure must be investigated. One way of doing this is to calculate proportion estimates based only on the information available at a particular stage. By comparing the accuracy at the different stages, one can determine which steps are necessary and which steps are not.

The classification procedure consists of the following steps:

a. Two sets of dots are labeled as corn, soybeans, or "other" by the analyst.

b. Using one set of analyst-labeled (type 1) dots as seed pixels, all pixels in the segment are grouped into clusters on the basis of their spectral values.

c. Each of the clusters is labeled as corn, soybeans, or "other" by the analyst-labeled type 1 dot closest to the mean of the cluster.

d. On the basis of the means and variances for each cluster, every pixel in the segment is classified as corn, soybeans, or "other."

e. Using the second set of analyst-labeled (type 2) dots as a random sample of the segment, the proportions based on the classification are corrected for any bias introduced by the classification process.

Proportion estimates can be calculated at the following four stages in the classification procedure:

a. At the dot labeling stage, the type 2 dots can be aggregated on the basis of their labels to determine a proportion.

b. At the clustering stage, a proportion can be determined by aggregating the pixels in a cluster on the basis of the label assigned to the cluster.

c. At the classification stage, a proportion can be determined by aggregating the pixels on the basis of the labels assigned by the classifier.

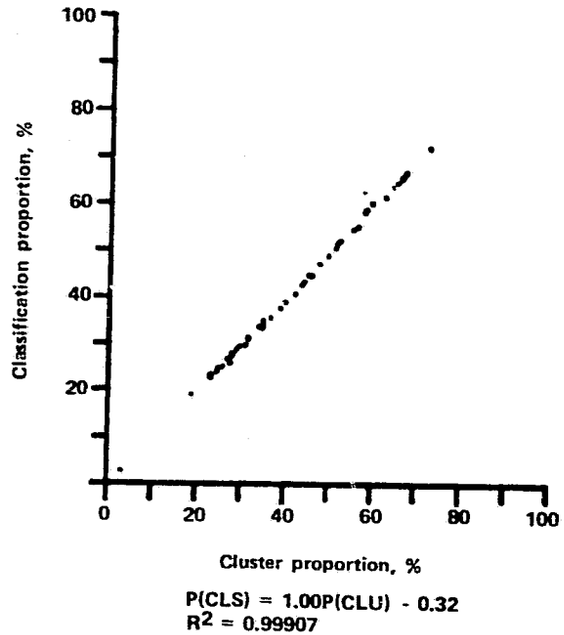
d. At the bias-correction stage, the final estimate produced by the procedure can be used.

The set of classifications used in this evaluation is listed in table 1. For the purposes of evaluating the classification process, five of the classifications were not used: 882 and 127 by group I; 881 by group II; 837 and 860 by group III. Eliminating these classifications resulted in each segment being represented twice by two different groups. Groups I and II were represented 17 times each, whereas group III was represented 16 times.

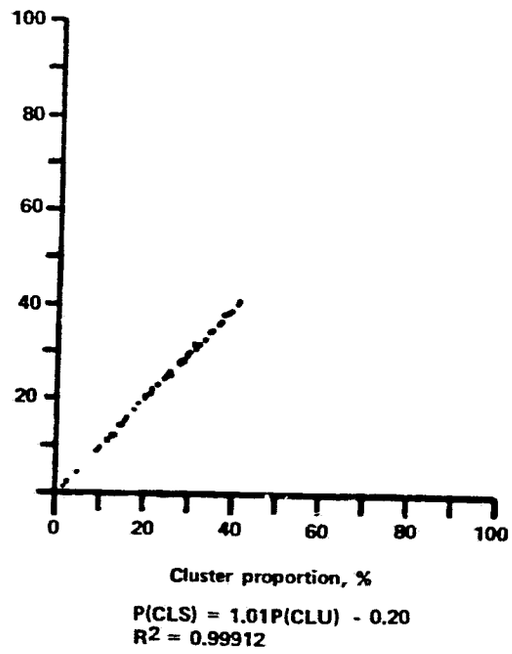
Although it is possible to determine a proportion at the clustering stage, clustering proportions are not presented. The cluster-based proportions are not included because the cluster and classification proportions are essentially identical. Figure 1 shows the classification proportions P(CLS) as a function of the cluster proportions P(CLU) for the segments involved in this evaluation. The linear regressions shown in the figure indicate an almost perfect correlation between the two proportion estimates (R^2 = 0.99907). Therefore, proportion estimates are calculated for the type 2 dots, classification, and bias-correction stages.

Figure 2 shows the errors in the proportion estimates as a function of the true proportion. The mean error, standard deviation, and mean square error for each estimator are presented in table 7 (page 3-7). The mean error is a measure of the bias in the estimator. The standard deviation is a measure of the estimator's variability. The mean square error is an indication of the overall performance of the estimator.

The mean error for corn was negative at the dot labeling and bias-correction stages and positive at the machine classification stage. The mean square errors were nearly the same at the dot labeling and bias-correction stages. This indicates that the machine processing did not improve the proportion estimate. The type 2 dots produced as good an estimate by themselves as when they were used to establish a bias-correction factor for the machine classification.

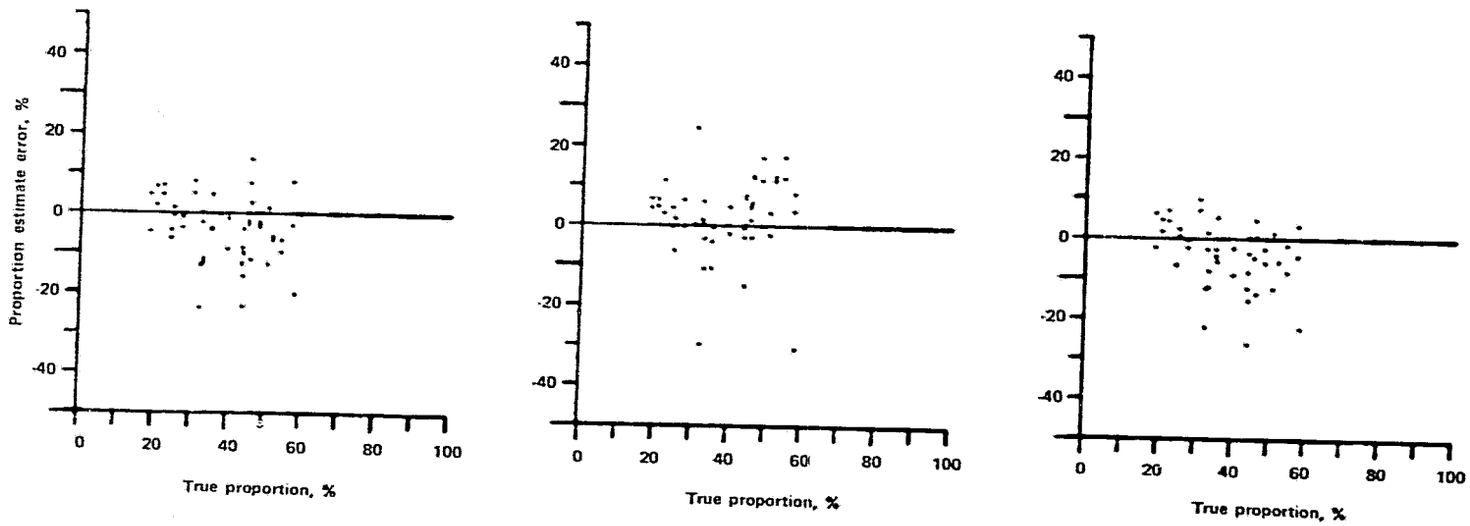


(a) Corn.



(b) Soybeans.

Figure 1.- Comparison between classification proportions and cluster proportions.

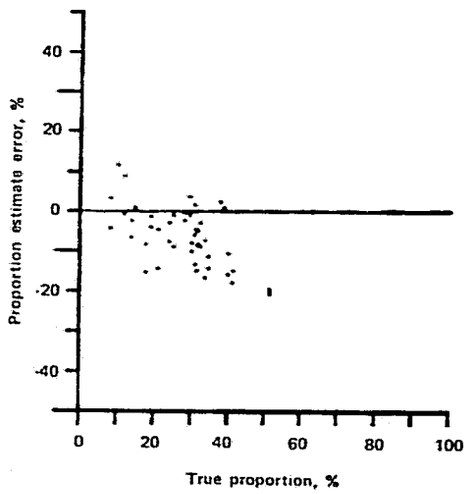


(a) Corn — dot estimate.

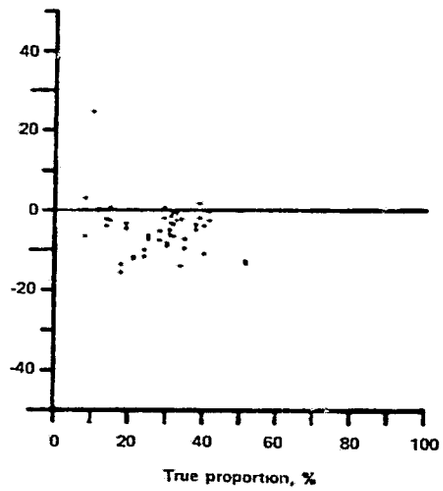
(b) Corn — classification estimate.

(c) Corn — bias-corrected estimate.

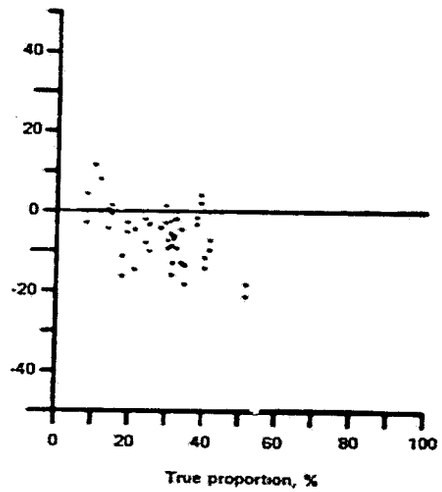
Figure 2.- Proportion estimates using analyst labeling as input.



(d) Soybeans — dot estimate.



(e) Soybeans — classification estimate.



(f) Soybeans — bias-corrected estimate.

Figure 2.- Concluded.

The mean error for soybeans was negative at all three stages. At the machine classification stage, the mean error and standard deviation were actually less than at the dot labeling and bias-correction stages. As in the corn estimates, the type 2 dots produced as good an estimate alone as when they were used to establish a bias-correction factor for the machine classification.

Table 8 shows the relative improvement in the estimate at one stage over that of the previous stage. The percentage of classifications improved and the mean improvement are indicated. The improvement is defined as the reduction in the absolute value of the error in going from one stage to the next. (For example, if the error at one stage was 5 percent and the error at a subsequent stage was -3 percent, then the improvement would be 2 percent.) These results are consistent with the results presented in table 7. If one uses the square root of the mean square error as a measure of the overall error at a given stage, the improvements are, in all cases, less than 20 percent of this value. Therefore, the machine processing has made a minimal change in proportion estimation accuracy.

The sources of the proportion errors can be separated into input errors in the form of mislabeled dots and errors in the proportion estimation procedure itself. In order to determine the amount of error introduced by the proportion estimation procedure, classifications were performed using ground-truth dot labels as input. The errors in these classifications are caused by the procedure alone. The results of these ground-truth-based classifications are shown in figure 3. The mean errors, standard deviations, and mean square errors are presented in table 9. Table 10 shows the improvements at the various stages in the process.

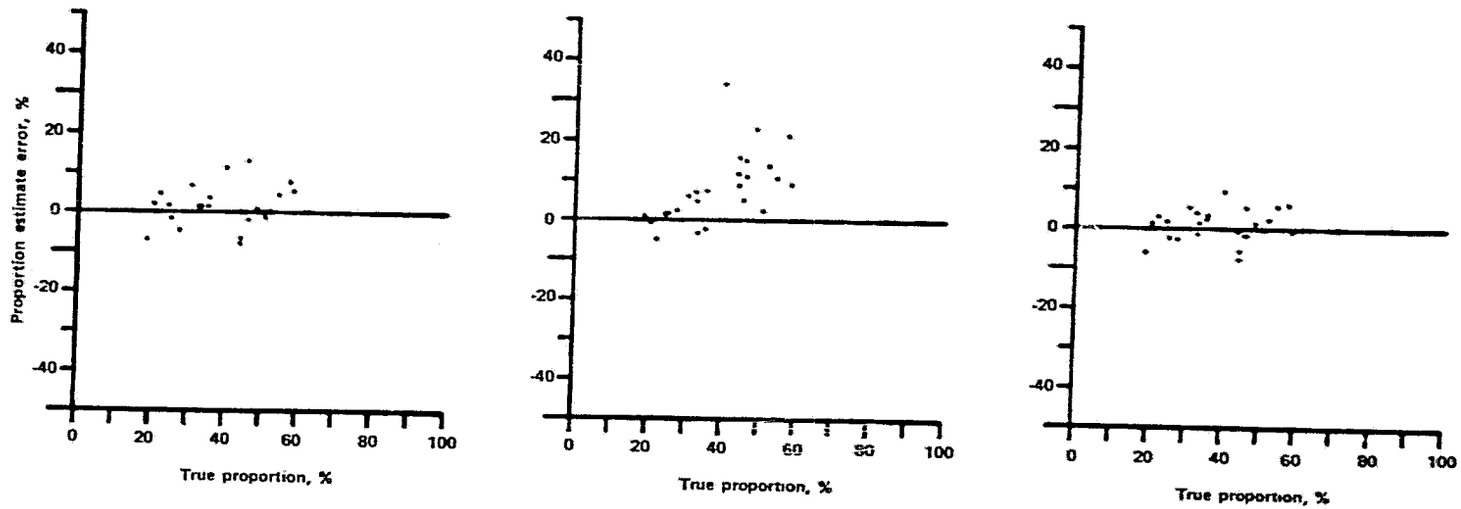
For both corn and soybeans, about 60 percent of the classifications had better bias-correction estimates than dot labeling estimates. However, the mean improvement was less than 1 percent. The bias-correction and dot labeling estimates are not significantly biased. Although there was an improvement between the dot labeling estimate and the bias-correction estimate, the

TABLE 7.- U.S. CORN AND SOYBEANS EXPLORATORY EXPERIMENT — CLASSIFICATION ERRORS

Source of classification	Corn			Soybeans		
	Mean error	Standard deviation	Mean square error	Mean error	Standard deviation	Mean square error
Type 2 dots as random sample	-3.71	8.15	78.9	-5.76	7.34	85.9
Machine classification	2.43	10.00	103.8	-4.67	6.33	61.0
Bias-corrected machine classification	-3.83	7.74	73.4	-5.80	6.91	80.4

TABLE 8.- U.S. CORN AND SOYBEANS EXPLORATORY EXPERIMENT — CLASSIFICATION IMPROVEMENT

Classification sources compared	Corn		Soybeans	
	Processing improved, %	Mean improvement	Processing improved, %	Mean improvement
Machine classification vs. type 2 dots	49	-0.34	55	1.36
Bias correction vs. machine classification	55	0.91	43	-1.24
Bias correction vs. type 2 dots	51	0.57	45	0.12

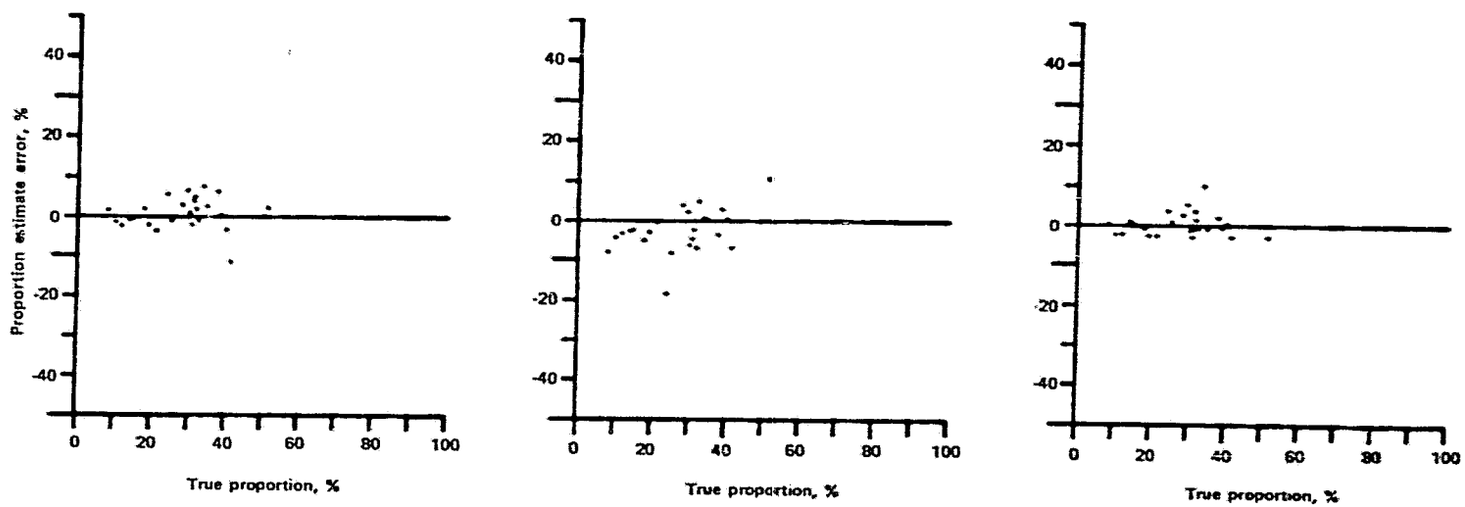


(a) Corn — dot estimate.

(b) Corn — classification estimate.

(c) Corn — bias-corrected estimate.

Figure 3.- Proportion estimates using ground-truth labeling as input.



(d) Soybeans — dot estimate.

(e) Soybeans — classification estimate.

(f) Soybeans — bias-corrected estimate.

Figure 3.- Concluded.

TABLE 9.- U.S. CORN AND SOYBEANS EXPLORATORY EXPERIMENT — CLASSIFICATION ERRORS USING GROUND-TRUTH LABELS AS INPUT

Source of classification	Corn			Soybeans		
	Mean error	Standard deviation	Mean square error	Mean error	Standard deviation	Mean square error
Type 2 dots as random sample	1.55	5.19	28.3	1.00	4.14	17.5
Machine classification	8.21	8.98	144.7	-2.28	5.63	35.6
Bias-corrected machine classification	1.00	4.07	17.0	0.47	3.08	9.3

TABLE 10.- U.S. CORN AND SOYBEANS EXPLORATORY EXPERIMENT — CLASSIFICATION IMPROVEMENT USING GROUND-TRUTH LABELS AS INPUT

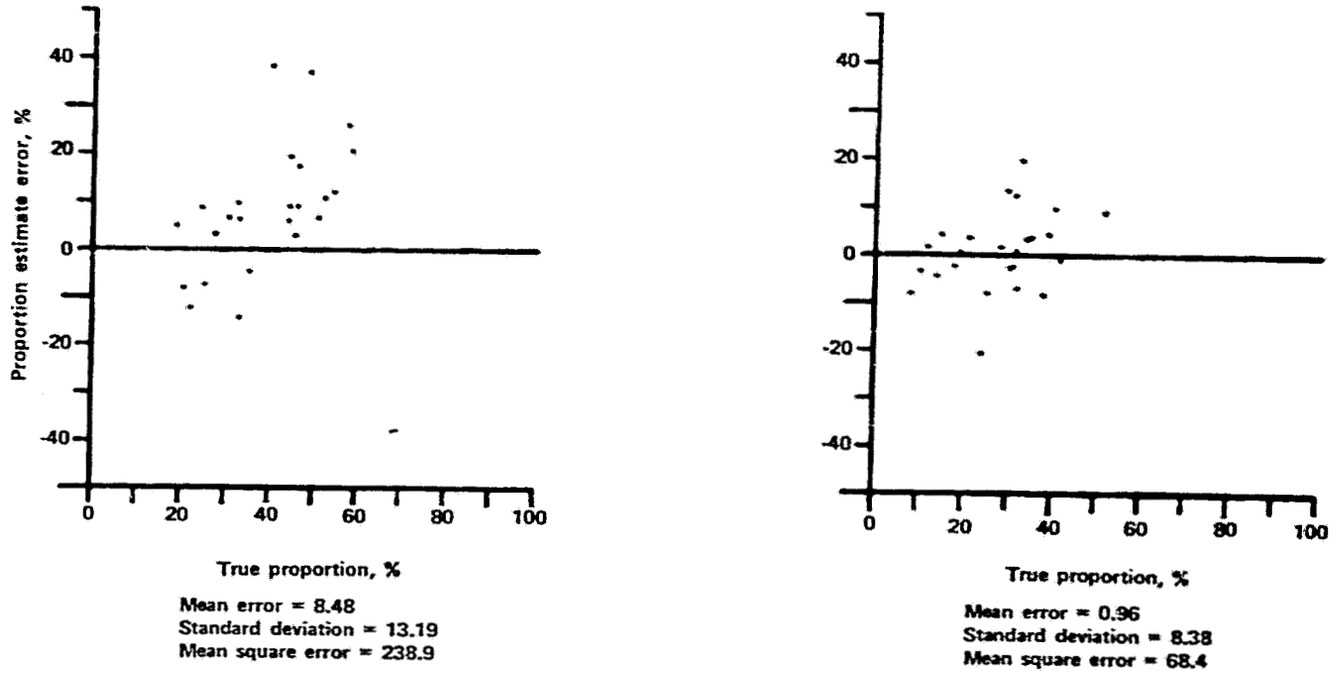
Classification sources compared	Corn		Soybeans	
	Processing improved, %	Mean improvement	Processing improved, %	Mean improvement
Machine classification vs. type 2 dots	20	-5.05	36	-1.26
Bias correction vs. machine classification	76	5.70	76	2.24
Bias correction vs. type 2 dots	60	0.65	64	0.98

improvement is not great enough to warrant the effort involved in performing the machine classification.

The most interesting feature of the ground-truth-based classification results is the large mean error in the machine classification proportions for corn. The plot in figure 3 shows that the error increases with increased true proportion. In fact, the mean square error of 144.7 (table 9) is larger than the mean square error of 103.8 for the analyst-based machine classification results (table 7). This indicates a serious problem with the procedure, since one would expect the results to improve or remain the same when true labels are substituted for analyst labels.

A possible source for the bias could be that the type 1 dots, used as input for the classification, are not representative of the entire segment. In order to determine if the type 1 dots are representative of the segment as a whole, a proportion estimate can be calculated using the type 1 dots as a random sample of the segment. If the type 1 dots are representative of the segment, the estimate should be unbiased. Figure 4 shows the proportion estimation error for the type 1 dots. As one might expect, the corn estimate has an 8.48-percent positive bias. This is very close to the bias of 8.21 percent in the classification estimate. The type 1 dot estimate shows the same trend as the classification estimate. Therefore, the type 1 dots are not representative of the segment, which is responsible for the bias in the classification results.

The question to consider now is: Why are the type 1 dots a biased sample of the segment? These dots are a set taken from a random grid; thus, the location should not produce a bias. One restriction was placed on the dots: that a dot which falls on a field boundary is not used. In this particular test, type 1 dots were used only if they were more than one-half pixel away from a field boundary. If the proportion is calculated using all of those pixels which meet the purity criterion and this estimate is biased with respect to the true proportion, then the purity restriction on the type 1 dots is the source of the observed bias. Figure 5 shows errors in the proportions based



(a) Corn.

(b) Soybeans.

Figure 4.— Proportion errors based on type 1 dots with ground-truth labels versus true proportions.

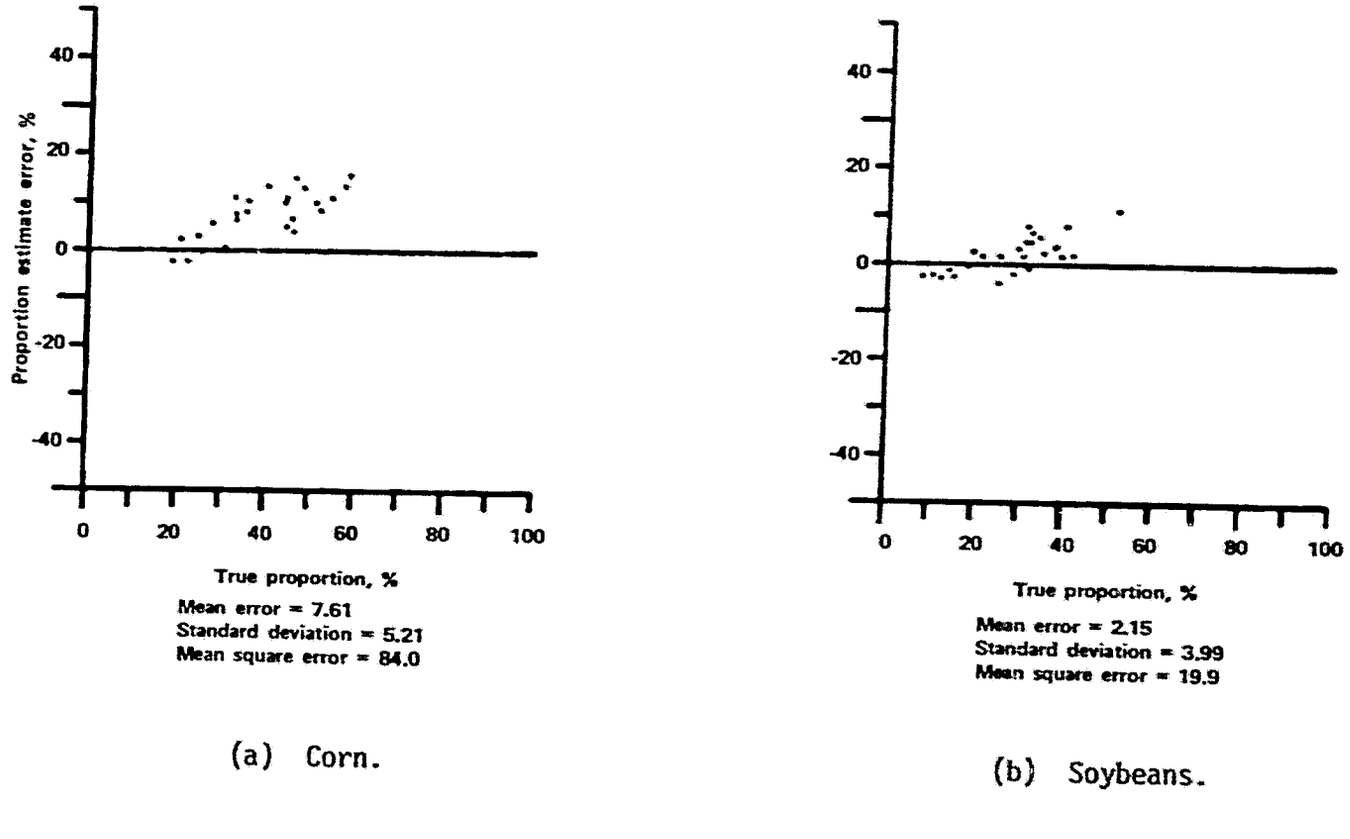
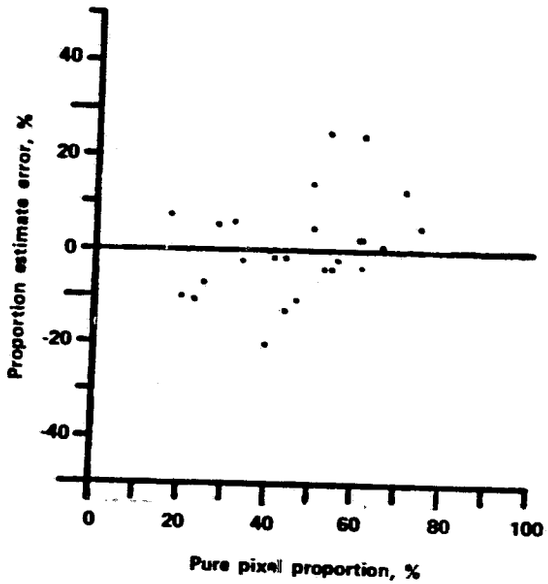


Figure 5.— Error in proportion estimate based on all pure pixels in scene versus true proportion. (A pure pixel is a pixel which is more than one-half pixel away from the field boundary.)

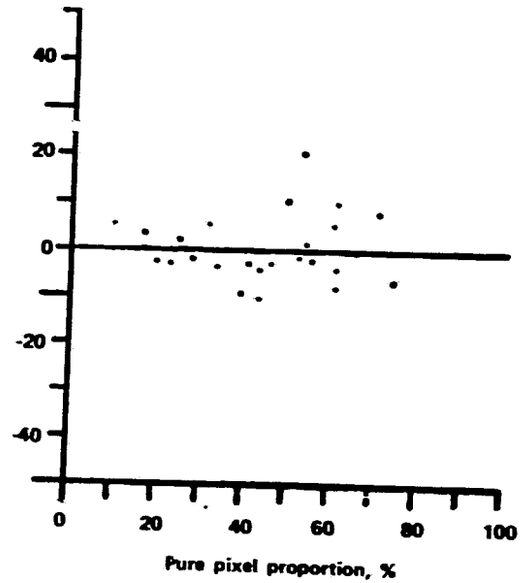
on all pure pixels in the segment as a function of the true proportion. The proportion errors for corn show the same trend to greater error with increased proportion, as seen in the type 1 dot proportion and classification results. The mean error for corn is 7.61 percent, which is consistent with the errors observed for the type 1 dot and classification estimates.

The conclusion from this analysis would be that the type 1 dots are more representative of the pure pixels in the scene than of the entire scene. Since the pure pixels are a biased sample of the segment, the proportions based on the type 1 dots and on the classification will also be biased. One way of verifying this conclusion is to compare the proportion estimates with the ground-truth proportions based on pure pixels. If the mean error, standard deviation, and mean square error are less when the pure pixel ground-truth proportion is used rather than the entire scene ground-truth proportion, then the proportions are more representative of the pure pixels than of the entire scene. Figure 6 shows the results of these comparisons. The corn estimates do not show the large positive bias evident when the entire scene proportion is used as the true proportion. The mean errors, standard deviations, and mean square errors corresponding to figure 6 are presented in table 11. The mean errors for the corn estimates are reduced from more than 8 percent to less than 1 percent. There was a slight reduction in the standard deviation. The mean square error was reduced by 50 percent or more. The results for soybeans were not as straightforward as those for corn. Although the mean square error for the type 1 dots decreased slightly when pure pixel proportions were used, the mean square error for the classification actually increased. These changes are not significant because the pure pixel and entire scene ground-truth proportions were close.

The bias and about one-half of the variability in the proportion estimates are the result of analyst dot labeling errors. A summary of the analyst dot labeling accuracy is shown in tables 12 and 13. The overall accuracy for type 1 dot labeling was 86 percent, whereas the accuracy for type 2 dot labeling was 75 percent. This is probably a consequence of the fact that all of the type 1 dots were pure, whereas type 2 dots could be impure. One can

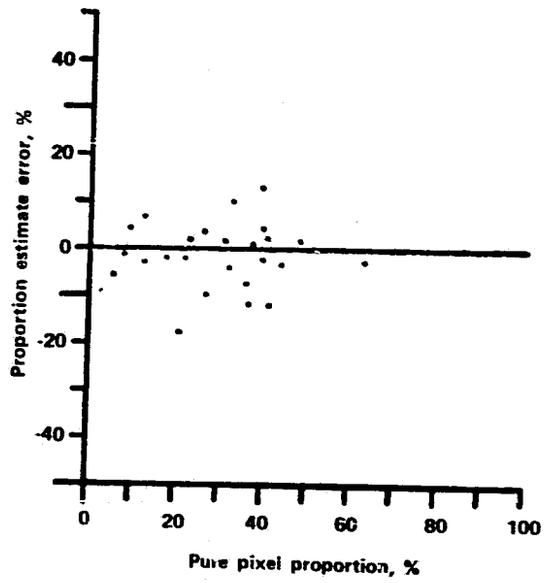


(a) Corn — type 1 dot estimate.

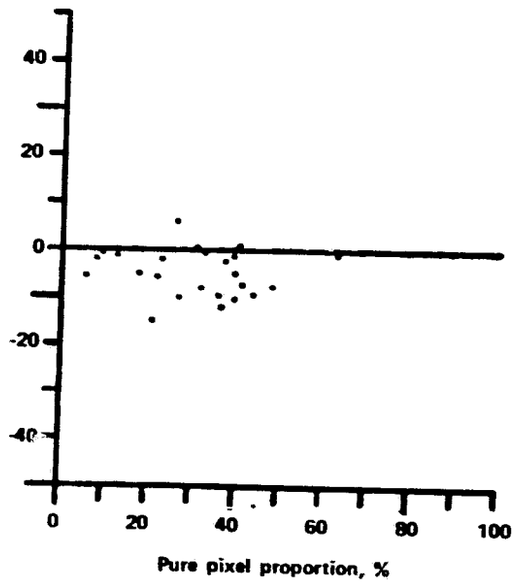


(b) Corn — classification estimate.

Figure 6.- Proportion estimate error using pure pixel proportions as true proportions (based on ground-truth labels for dots) versus pure pixel proportions.



(c) Soybeans — type 1 dot estimate.



(d) Soybeans — classification estimate.

Figure 6.- Concluded.

TABLE 11.- EFFECT OF USING PURE PIXEL GROUND-TRUTH PROPORTIONS ON CLASSIFICATION ERRORS

Crop	Source of classification estimate	Source of ground-truth proportion	Mean error	Standard deviation	Mean square error
Corn	Type 1 dots as random sample	Entire scene	8.48	13.19	238.9
		Pure pixels	.93	10.69	110.6
	Machine classification	Entire scene	8.21	8.98	144.7
		Pure pixels	.66	7.32	51.9
Soybeans	Type 1 dots as random sample	Entire scene	.96	8.38	68.4
		Pure pixels	-1.18	6.97	48.0
	Machine classification	Entire scene	-2.28	5.63	35.6
		Pure pixels	-4.41	4.93	42.8

TABLE 12.- DOT LABELING ACCURACY FOR TYPE 1 DOTS

Crop	Dots labeled corn	Dots labeled soybeans	Dots labeled "other"	Dots correctly labeled, %
Corn	647	34	71	86
Soybeans	54	392	52	79
"Other":				
Wheat	3	0	23	88
Oats	1	0	8	89
Grass	0	1	7	88
Hay	3	2	40	89
Pasture	7	1	138	95
Trees	6	1	142	95
Clover	0	0	9	100
Vegetable	0	0	2	100
Water	0	0	14	100
Nonagriculture	1	3	41	91
Homestead	1	0	27	96
Idle	3	2	35	88
Total "other"	25	10	486	93

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TABLE 13.- DOT LABELING ACCURACY FOR TYPE 2 DOTS

Crop	Dots labeled corn	Dots labeled soybeans	Dots labeled "other"	Dots correctly labeled, %
Corn	1598	124	456	73
Soybeans	231	1014	341	64
"Other":				
Wheat	11	11	93	81
Oats	14	3	64	79
Grass	6	3	22	71
Hay	6	8	124	90
Pasture	47	18	421	87
Trees	18	8	343	93
Clover	4	2	5	45
Vegetable	0	0	9	100
Water	2	0	35	95
Nonagriculture	12	10	131	86
Homestead	7	6	95	88
Idle	21	13	119	78
Total "other"	148	82	1461	86

explain the fact that the soybean proportion estimates based on classification results were better than those based on the type 2 dots when analyst labels were used. Although the classification estimates are usually less accurate, the better labeling for the type 1 dots was enough to improve the classification results. In looking at the confusion between the categories (corn, soybeans, and "other"), it appears that there is greater confusion between corn and "other" than between corn and soybeans.

In order to determine how well the clustering algorithm is working in separating the crop of interest from a noncrop, the cluster purities were calculated for corn and for soybeans. Histograms of cluster purity are shown for corn and soybeans in figures 7 and 8. The number of clusters with given crop proportions is plotted as a function of the crop proportion. Ideally, these histograms should show two maxima (at 0 percent and 100 percent) representing pure noncrop and crop clusters. The histogram should be zero at the center. In the figures, one does see the expected two maxima with a minimum of approximately 50 percent. The crop maximum is fairly broad, but it appears that the clustering algorithm is separating crop and noncrop pixels to a certain extent.

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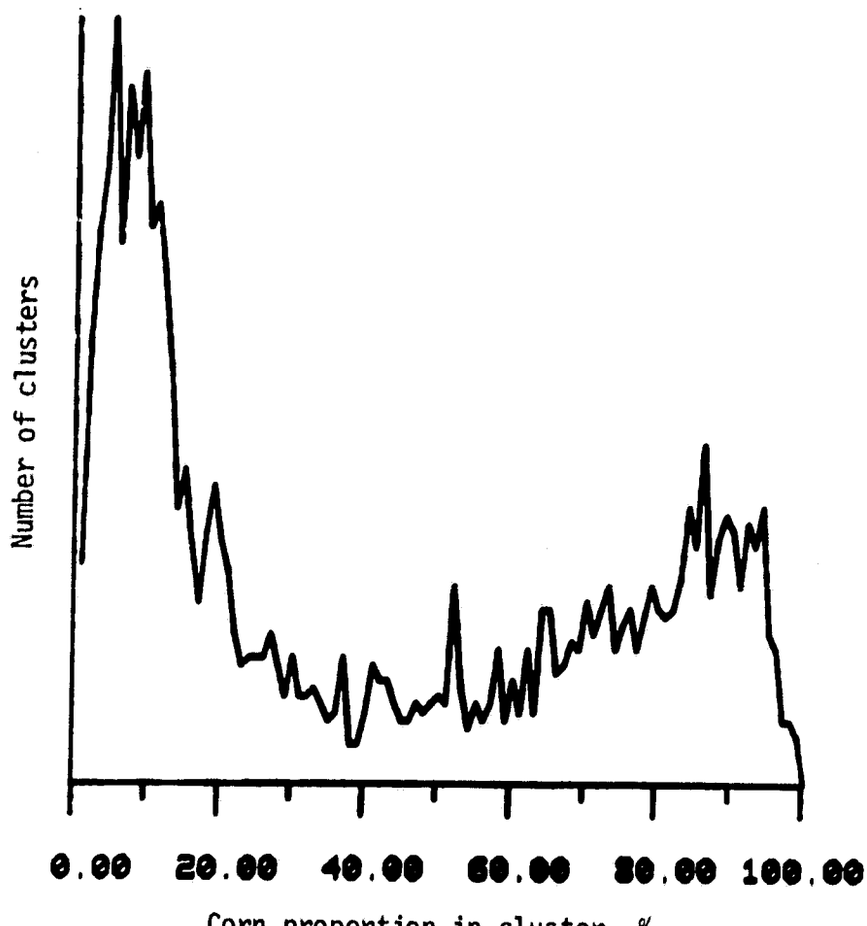

Figure 7.- U.S. Corn and Soybeans Exploratory Experiment histogram of cluster purity for corn.

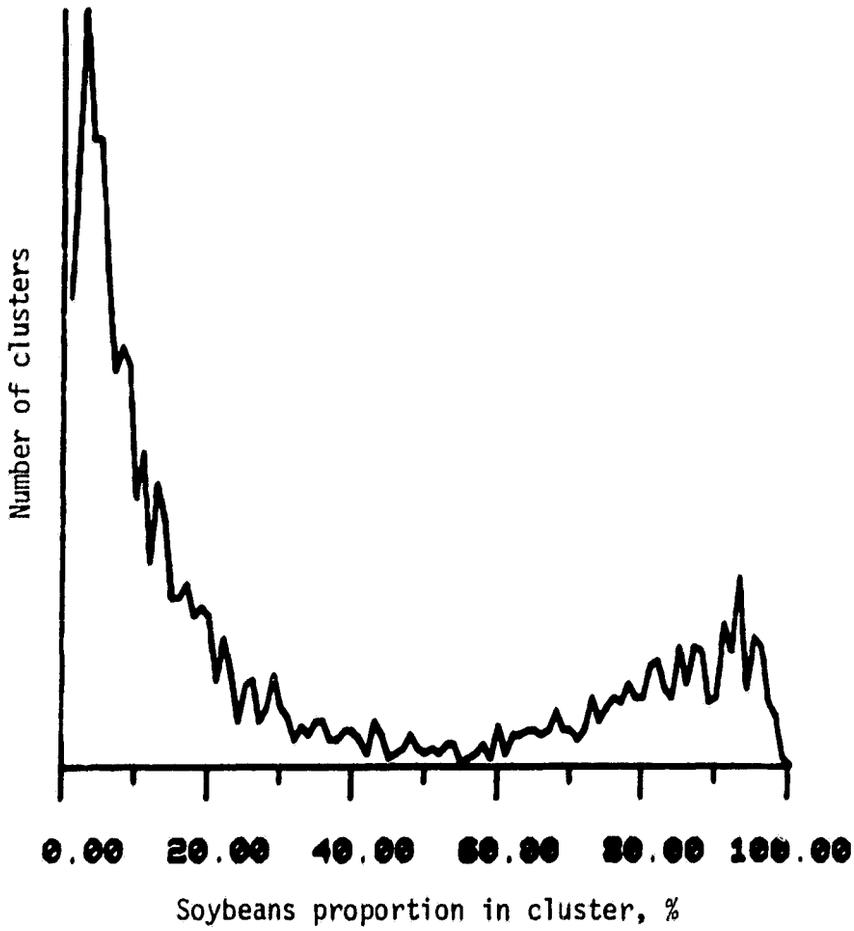

Figure 8.- U.S. Corn and Soybeans Exploratory Experiment histogram of cluster purity for soybeans.

4. SUMMARY OF RESULTS

Based on the studies presented in this document, the following conclusions can be reached:

a. The proportion estimates for corn had a bias of -4 percent with a standard deviation of 8 percent.

b. The proportion estimates for soybeans had a bias of -6 percent with a standard deviation of 7 percent.

c. The bias and about one-half the standard deviation for both corn and soybeans were the result of dot labeling errors.

d. Proportion estimates based on the type 2 dots as a random sample are as good as the final bias-corrected results.

e. The machine classification results are identical to the machine clustering results.

f. The large bias observed in the classification proportions for corn (when true labels are used) is caused by bias in the type 1 dots used as input to the classification procedure.

g. The bias in the type 1 dots was present because the type 1 dots were required to be pure.

h. Although the three groups used to process the segments were given identical training and used identical procedures, one group had significantly different dot labeling accuracy.

i. It is more difficult to label "other" dots in APU 14 than it is in APU's 25 and 28.

5. RECOMMENDATIONS

Dot labeling errors are the greatest source of error in the proportion estimates. If the quality of the proportion estimates is to be improved, the current dot labeling techniques need to be improved or an alternative for dot labeling found.

Since the machine processing used in this test does not significantly improve the accuracy of the corn and soybeans proportion estimates, the proportion estimates can be made using the labeled dots as a random sample of the segment. Alternatives to the machine processing technique used in this test should be investigated to see if a more effective technique can be found.

Since the maximum likelihood classification results are identical to the results using labeled clusters, it is not necessary to perform the maximum likelihood classification. The proportion estimates based on the clustering results should be bias corrected using a random dot set so that the kind of bias reflected in the corn proportion estimates can be reduced.

6. REFERENCES

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